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OFFICE OF CONTRACT ADMINISTRATION
SPONSORED PROJECT INITIATION

Date: April 4, 1977

Project Title: *Coordinated Observations of Lower Thermospheric Circulation*

Project No: *E-16-614*

Project Director: *Dr. Robert G. Roper*

Sponsor: *National Science Foundation*

Agreement Period: From *2/15/77* Until *7/31/79*
(24-month budget period plus flexibility period)

Type Agreement: *Grant No. ATM76-81558*

Amount:
$39,000 NSF
1,222 GIT (E-16-384)
$40,222 Total

Reports Required:
Annual Letter Technical; Final Technical Report

Sponsor Contact Person (s):

Technical Matters

Contractual Matters
(thru OCA)

Mr. Stephen J. Franko
Grants Officer
National Science Foundation
Washington, D. C. 20550

Defense Priority Rating: *none*

Assigned to: *Aerospace Engineering* (School/Laboratory)

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- Other

CA-3 (3/76)

GEORGIA INSTITUTE OF TECHNOLOGY
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SPONSORED PROJECT TERMINATION

Date: November 13, 1979

Project Title: Coordinated Observations of Lower Thermospheric Circulation

Project No: E-16-614

Project Director: Dr. Robert G. Roper

Sponsor: National Science Foundation

Effective Termination Date: 7/31/79

Clearance of Accounting Charges: 7/31/79

Grant/Contract Closeout Actions Remaining:

TERMINATED

_ Final Invoice and Closing Documents
X Final Fiscal Report
_ Final Report of Inventions
_ Govt. Property Inventory & Related Certificate
_ Classified Material Certificate
_ Other ______

Assigned to: Aerospace Engineering (School/Laboratory)

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CA-4 (1/79)

E-16-617

GEORGIA INSTITUTE OF TECHNOLOGY
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SCHOOL OF AEROSPACE ENGINEERING

DANIEL GUGGENHEIM SCHOOL OF AERONAUTICS

~~XXXXXXXXXXX~~
February 2, 1978

Dr. H. C. Carlson
Atmospheric Sciences (Aeronomy)
NSF, Room 312
1800 G Street NW
Washington, DC 20550

Subject: Annual Technical Letter, Grant No. ATM76-81558 "Coordinated Observations of Lower Thermospheric Circulation". Reporting Period: February 15, 1977 - February 14, 1978

Dear Herb:

Four major achievements in international cooperation have resulted from the effort expended under the first year of this grant.

1) Ten papers detailing the results of the first three URSI/IAGA Cooperative Tidal Observations Program (CTOP) Coordinated Observational Intervals (August 1974, October 1975, and January 1976) have been reviewed and edited for publication in the Journal of Atmospheric and Terrestrial Physics (see attachments).

2) In collaboration with Dr. S. Kato, of the University of Kyoto, a symposium "Electric Currents and Atmospheric Motion in the Lower Thermosphere" was convened at the Joint IAGA/IAMAP Assembly in Seattle, Washington, August 1977. Some fifty papers were given in five half-day sessions, including a paper by the principal investigator and Dr. G. Hernandez of Fritz Peak Observatory comparing Atlanta radio meteor winds with airglow (oxygen green line) winds in the same altitude range. A selection of the better papers is currently being reviewed by the principal investigator for publication in the Journal of Geomagnetism and Geoelectricity.

   In connection with this symposium, I would like to place on record a procedure which, in this instance at least, I believe to be primarily responsible for the attendance of two Soviet scientists who made significant contributions to the symposium. Letters of invitation were sent not only to the scientists in question, but also to the Directors of their Institutes, and the President of the Soviet Geophysical Committee, twelve months in advance of the meeting (I learned at the IUGG meeting in Grenoble in 1975 that at least eight months advance notice is required). While this procedure may not guarantee the attendance of a prospective contributor, my previous experiences would say that anything less will undoubtably fail.

3) Funds from this grant have enabled the furtherance of the long term cooperation between the principal investigator and the Radio Meteor Group at the

University of Adelaide, South Australia. A computer program has developed which produces height/time plots of the annual variation of the winds from 80 to 100 km altitude from the data produced at a given meteor radar location. The amplitudes of the annual and semiannual waves in the prevailing and tidal winds are determined as a function of altitude. This program is being applied to the data from Atlanta (34°N) and Adelaide (35°S).

4) An unprecedented opportunity for international cooperation has arisen with the installation by the French of a meteor wind radar on Puerto Rico. This radar is currently being operated in coordinated campaigns with the Arecibo Radio Observatory (as well as the Georgia Tech and University of New Hampshire meteor wind radars). Campaigns have been arranged to coincide with the CTOP calendar for 1978 (attached). A separate proposal has been made to NSF for the continued operation of the French radar on Puerto Rico beyond its current dedication. A year of continuous operation has been proposed. This would provide a unique set of badly needed equatorial mesopause circulation data.

Although previously communicated to you on October 21, 1977, I am also attaching copies of my report to IAGA Division V as given at the Seattle Assembly, together with my current mailing list for coordinated activities. In addition to the meteor radar/IS stations, and the ties that already exist with the European/Soviet Union E layer drifts network (Drs. Sprenger and Kasimirovsky), communication has also been established with the Lamont Doherty team investigating stratospheric and lower thermospheric tidal winds using infrasound (Drs. Rind and Donn), a technique which is also being pursued at the University of New Hampshire (Dr. Frost).

Links have also been established with those responsible for the development of the VHF Mesosphere/Stratosphere/Troposphere backscatter radar (Dr. Van Zandt). As discussed at the recent Workshop on the use of Radar in Atmospheric Science held at Utah State University in December 1977 (the attendance of the principal investigator at this meeting was funded by NSF, but not out of the subject grant), and as is stressed repeatedly in the Middle Atmosphere Planning Document published last year by SCOSTEP, further advances in our understanding of the middle atmosphere hinge vitally on cooperation between individual experimenters using a variety of techniques.

The first year of this grant has been highly productive, and I anticipate the coming year being even moreso. I am particularly excited about the possible collaboration with the French on Puerto Rico.

Respectfully submitted,

Dr. R. G. Roper
Principal Investigator

Journal of Atmospheric and Terrestrial Physics

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From the Editor-in-Chief,
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6th December 1977

Dr. R. G. Roper
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Dear Dr. Roper,

Many thanks for the ten CTOP papers which I have received via Professor Bowhill. In view of Sir Granville's absence (in Antarctica) until mid-February we sought an independent referee's report on the paper by Baggaley and Poulter. He said the description of the equipment was useful and it was also desirable to have something from the S. hemisphere, but admitted that if it had been submitted on its own it would have been turned down.

The paper has therefore been included and the ten manuscripts have to-day been sent to the publishers - list enclosed. I have asked them to let me have some indication as to when they are likely to appear in print and given them your name as co-ordinator in case there should be any further queries.

Yours sincerely,

K. WHITAKER (Mrs)
Secretary

c. c. S. A. B.

Journal of Atmospheric and Terrestrial Physics

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Oxford

Review of CTOP Collected Papers

No. 4040
Preliminary Results from the URSI/IAGA Cooperative Tidal Observations Program (CTOP) - R. G. Roper and J. E. Salah

No. 4041
Coordinated Tidal Observations at Arecibo - R. M. Harper and R. H. Wand

No. 4042
Winds from the Atlanta (34°N, 84°W) Radio Meteor Wind Facility - R. G. Roper

No. 4043
Urbana Meteor Radar Observations during GRMWSP/CTOP Periods - G. C. Hess and M. A. Geller

No. 4044
Meteor Wind Data from Global Comparisons - Ronald R. Clark

No. 4045
Tidal Observations at Millstone Hill for the August 1974 and October 1975 Special Periods - R. H. Wand and J. E. Salah

No. 4046
Meteor Winds over Sheffield (53°N, 2°W) - S. P. Kingsley, H. G. Muller, L. Nelson and A. Scholefield

No. 4047
The French Meteor Radar Facility - M. Glass, R. Bernard, J. L. Fellous and M. Massebeuf

No. 4048
Incoherent Scatter Results for Coordinated Special Intervals at St. Santin (France) - R. Bernard

No. 4049
The Radio Meteor Wind Facility at Christchurch, New Zealand - W. J. Baggaley and E. M. Poulter

10 papers to be published in one batch in this order

Sent to Pergamon Press: 5th December 1977

INTERNATIONAL UNION OF GEODESY AND GEOPHYSICS
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Dr. R.G. Roper,
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To: All GRMWSP/CTOP Members
and interested parties.

October, 1977

Subject: GRMWSP/CTOP Calendar for 1978

Enclosed is a copy of the subject calendar, which is based on recommendations made in working group meetings at the IAGA/IAMAP Joint Assembly in Seattle last month, and feedback on those recommendations received since.

Emphasis is being placed on three Global Intervals this year (with hopefully all radio meteor and IS stations operating). These have been divided into one primary and two secondary intervals, the distinction being made in the hope that stations which cannot schedule all three intervals will concentrate on the primary interval June 1 through 14 inclusive.

While all stations are encouraged to make regular observations centered around World Days each month, the question of day to day variability and the importance of phenomena with periods greater than a day will only be clarified by long observational periods. Hence next years emphasis on long runs.

Don't forget that the last run for 1977 is December 5 - 16 (G: 6 - 9).

Dr. Robert G. Roper
GRMWSP/CTOP Coordinator

1978 Calendar

URSI/IAGA Coordinated Tidal Observation Program

G March 2 - 15

G* June 1 - 14

G July 27 - August 9

G Global Observation Period - all meteor wind and IS radars operational for as long as possible during these intervals.

* Primary Observation Period

Dr. R. G. Roper
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IAGA Division V, Working Group 2
(Meteor Observatories)

Report presented by R. G. Roper at the
Joint IAGA/IAMAP Assembly, Seattle, August 22 - September 3, 1977

As with my first report as chairman of this working group (presented at the Grenoble IUGG meeting in 1975), most of this report is addressed to radio meteor wind determination. However, one of the reasons why I suggested that the initially proposed group title "Radio Meteor Observatories" be changed to "Meteor Observatories" was that I envisaged the group as serving not only IAGA's self interests, but also as a liason with other associations and Unions with an interest in meteor astronomy and meteor physics, particularly as these relate to interactions with the earths atmosphere. In this context, members of W. G. 2 have participated in a joint IAU/IAGA "Committee on Radar Observations of Meteor Rates and Radiants, and Anomalies at the Base of the Thermosphere". Since the interest of IAU Commission 22 (the original proposers of the Joint Committee) lie solely in the meteor patrol (rates and radiants) area (as reported by Chairman C. S. L. Keay at the Grenoble Assembly of IAU in August 1976), our input to this committee has been minimal

However, close ties have been forged with experimenters using other techniques; in particular with the Incoherent Scatter Group G. 8 of URSI Commission III through the joint Cooperative Tidal Observations of the Lower Thermosphere Program (CTOP), and the Ionospheric Drift Observations Group G. 2 of URSI Commission III who, together with IAGA's Global Radio Meteor Wind Studies Project (GRMWSP), are now using the same observational calendar.

Reports have been received detailing the most recent operations of the Italian CNR Meteor Radar Station at Budrio (44.5° N, 11.7° E)(Dr. F. Verniani) and of the iminent completion of an excellently conceived meteor wind radar by the Ionosphere Research Laboratory of the University of Kyoto (Dr. T. Aso).

Communications have been received from Dr. A. Frost (University of New Hampshire) and Dr. D. Rind (Lamont Doherty Geological Observatory) concerning the use of infrasound recording techniques to deduce the wind field in the lower thermosphere. They are anxious to make comparisons with radio meteor and other lower thermosphere wind determinations.

The URSI/IAGA CTOP venture has resulted in the following papers, detailing results of the first three cooperative periods (9-14 August, 1974; October 13-17, 1975; January 19-23, 1976), which are being considered for publication in the Journal of Atmospheric and Terrestrial Physics:

Roper, R. G., and J. E. Salah, "Preliminary Results from the URSI/IAGA Cooperative Tidal Observations Program (CTOP)".

Harper, R. M., and R. H. Wards, "Coordinated Tidal Observation at Arecibo".

Roper, R. G., "Winds from the Atlanta (34° N, 84° W) Radio Meteor Facility".

Hess, G. C., and M. A. Geller, "Urbana Meteor Radar Observations During GRMWSP/CTOP Periods".

Clark, Ronald R., "Meteor Wind Data for Global Comparisons".

Ward, R. H., and J. E. Salah, "Tidal Observations at Millstone Hill for the August 1974 and October 1975 Special Periods".

Kingsley, S. P., H. G. Muller, L. Nelson, and A. Scholefield, "Meteor Winds Over Sheffield (53° N, 2° W)".

Glass, M., R. Bernard, J. L. Fellows and M. Massebeuf, "The French Meteor Radar Facility".

Bernard, R., "Incoherent Scatter Results for Coordinated Special Intervals at St. Santin, France".

Baggaley, W. J., and E. M. Poulter, "The Radio Meteor Wind Facility at Christchurch, New Zealand".

With the publication of the SCOSTEP Middle Atmosphere Program (MAP) Planning Document (available from the Aeronomy Laboratory, Department of Electrical Engineering, University of Illinois, Urbana, Illinois 61801, U.S.A.), which calls for greatly increased cooperation between experimenters using ground based, in situ and satellite techniques, an even greater need exists for such collaborative endeavours as GRMWSP and CTOP.

At our working group meeting last Tuesday night, discussions centered around the need for longer observational intervals in order to determine the importance of day to day variability on a global scale. To this end, a primary Global Observational Interval, June 1 to June 14, 1978, was proposed for CTOP.

To increase our knowledge of equatorial upper atmosphere dynamics, the French portable radar has been located at Puerto Rico as part of a colaborative program with the incoherent scatter facility at the Arecibo Observatory.

At the working group meeting, discussions were held with Ray Conkright of World Data Center A regarding the archiving of radio meteor wind data. A proposed data format will be circulated by the chairman later this year.

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FINAL TECHNICAL REPORT
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COORDINATED OBSERVATIONS OF LOWER THERMOSPHERIC CIRCULATION

Prepared by

R. G. Roper

Prepared for

ATMOSPHERIC RESEARCH SECTION
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COORDINATED OBSERVATIONS OF LOWER THERMOSPHERIC CIRCULATION

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CONTENTS

Coordinated Observations of Lower Thermospheric Circulation

Abstract

The objective of this two year grant was to continue the coordinated observations of lower thermospheric circulation being carried out by a global network of meteor wind facilities and incoherent scatter radars under the auspices of IAGA and URSI, and to ensure the collection, interpretation, and publication of the results as they pertain to global neutral atmosphere motions in the height range 80 to 120 kilometers, with due regard being given to interaction with the lower and higher atmosphere.

This objective has been achieved with

a) the collection, editing (with Dr. J. E. Salah of M.I.T.) and publication of the first ten URSI/IAGA Cooperative Tidal Observations Program (CTOP) papers, which appeared in the Journal of Atmospheric and Terrestrial Physics for August, 1978,

b) the co-convening, with Professor Susumu Kato of the University of Kyoto, of the symposium on "E Region Motion and Electric Currents" held at the Joint IAGA/IAMAP Assembly in Seattle, August, 1977. The best of the papers presented have been collected and published in the Journal of Geomagnetism and Geoelectricity (in press, 1979), and

c) the continuing collaboration of workers in this field in observing the CTOP calendars.

While continuation of collaboration during specified (limited) observational periods is needed for those experiments that cannot be carried out continuously, the need for continuous operation of meteor wind radars is stressed. Such operation is the norm for those stations in the U.S.S.R. run by the Soviet Hydrometeorological Service. Other nations are encouraged

to provide similar support.

Publications under this grant:

"Preliminary results from the URSI/IAGA cooperative tidal observations program (CTOP)" by R. G. Roper and J. E. Salah, J. Atmos. Terrest. Phys., 40, 879-885, 1978.

"A comparison between radio meteor and airglow winds" by G. Hemandez and R. G. Roper, J. Geomag. Geoelec. 1979 (in press).

PREFACE

UPPER ATMOSPHERE INVESTIGATIONS REQUIRE COORDINATED APPROACH

A Statement by the American Meteorological Society,
Prepared by its Committee on Atmospheric Problems of
Aerospace Vehicles

A pressing need exists for a coordinated scientific effort to probe and define the nature of the atmosphere at altitudes from 50 to 200 km. Further knowledge of the physical structure, composition, and circulation of this region, comprising the mesosphere and lower thermosphere, is essential to the economical design and effective operation of aerospace vehicles.

Lower layers of the atmosphere are sounded daily up to about 30 km by balloon-borne radiosondes released from hundreds of weather stations. Between 30 and 60 km, increasingly frequent measurements are being made by means of instruments ejected from the relatively inexpensive rockets fired at nearly a dozen ranges comprising the Meteorological Rocket Network. Thus, weather maps can now be drawn for levels as high as the 0.4-mb surface (at about 55 km or 180,000 feet). Far beyond, in the high layers above 200 km, many of the satellites orbited since 1957 continue to supply large amounts of physical information.

In the great intervening layer, however, relatively few atmospheric observations have been made because rockets capable of penetrating the mesopause are very costly while satellite orbits with perigees below 200 km decay in a matter of days. Most of the presently insuffucient information comes from the photography of chemo-luminescent rocket trails and from rocket-borne instruments such as the pressure gauge, electron densitometer, and mass spectrometer. Indirect information comes from ground-based ionosonde measurements, photographic and radar tracking of meteor trails, and a few specialized photometric and spectrographic measurements of radiation absorbed or emitted in this region.

Important problems exist which cannot be satisfactorily resolved with the present grossly inadequate knowledge of atmospheric phenomena in the major layers above and below the mesopause. For example, lack of any sort of synoptic climatology for this region allows large errors to appear in aerospace vehicle responses, since conditions may deviate significantly from the Standard Atmosphere. Costly overdesign of hypersonic aircraft and re-entry vehicles might result from inaccurate information on the horizontal and vertical distributions of density and wind.

Gravity waves and noctilucent-cloud particles could conceivably have the same ill effects on hypersonic vehicles traversing these regions that clear air turbulence and hail at lower levels have on conventional aircraft. Other physical phenomena of significance to aeronomers and aerospace designers are also of rapidly increasing interest to meteorologists. These include the inter-relations between ionospheric disturbances, proton showers, electron densities, extreme ultraviolet radiation, X-rays, solar disturbances, etc., and their effects upon materials, communications, and personnel exposed above 50 km altitude.

There are many important phenomena in the 80-120 km altitude region, most of which are only partly understood. Molecular dissociation is known to occur to an appreciable degree above 100 km. The turbopause, a thin boundary layer in the vicinity of 105 km, marks the top of a turbulent regime and separates it from smooth flow above in the region where diffusive separation becomes a dominant process. Substantial enhancements of ionization (Sporadic E) often appear at about 100-110 km. In the auroral high-latitude zones, occasional penetration of solar particle radiation down to a height of 60-80 km greatly increased D-region ionization and is suspected of having a profound effect on the neutral atmosphere as well.

Above the mesopause itself, a boundary region of very low temperatures observed around 90 km, only meager information has been provided. Despite the low density and pressure of the mesopause--about a millionth of the sea level values--its structure and that of the closely adjacent layers are extremely complicated. It is the coldest region in the earth's atmosphere, apparently varying in temperature from 140K to 220K (-130C to -50C, or -200F to -60F), depending on latitude and season. This contrasts with the much warmer stratopause at about 50 km (165,000) feet, where the absorption of radiation by ozone can produce temperatures approaching summer-time values at the earth's surface. Above the mesopause, temperatures increase rapidly to thermospheric values of 600K to 2100K (600F to 3300F) at heights of several hundred kilometers; here the temperature varies markedly from day to night, and even more through the 11-year cycle in solar activity.

In many respects, the mesopause is an interface between two regions studied by different disciplines; meteorology and aerodynamics below, aeronomy and ionospheric physics above. Hence, in the past it has suffered the usual fate of a boundary region: conflicting terminology, incompatible measurements, irreconcilable theories, and lack of communication between investigators. Even direction of gaseous motion are reported differently; according to the direction from which it comes by meteorologists, according to the direction toward which it goes by many physicists. Rather than use the thermally-based meteorological terms, mesosphere and thermosphere (separated by mesopause) ionospheric physics speak of the D, E, and F layers of the ionosphere at 60-90, 90-140, and above 140 km, respectively.

The mesopause resembles the tropopause in many respects, and presumably is at least as complicated. If the structure of the tropopause proves to be a true analog, then we may expect eventually to find that the temperature minimum of the mesopause level actually occurs in "leaves" having different elevations over different latitude zones. Where these leaves overlap at zone boundaries, jet streams like those along lines of overlapping tropopauses may be found through intensive interdisciplinary research.

Noctilucent clouds, a phenomenon found to occur near the mesopause, are a most perplexing feature of the upper atmosphere. Seen most commonly in summer in polar and sub-polar regions, they apparently are ice-crystal clouds formed by ascending water vapor condensing on descending meteoritic dust.

The turbopause is another phenomenon that appears to have some connection with the mesopause although it is usually found at a level 10 to 15 km higher. Below the turbopause, rocket trails bulge and twist as a result of turbulent eddy motions while above it, rocket trails are smooth and cylindrical, dissipating only through molecular diffusion. In the "homosphere" below the turbopause, composition and hence molecular weight are virtually constant. In the so-called "heterosphere" above this boundary, the molecular weight of air decreases with height due to the upward diffusion of the lighter atomic gases, formed in this region by the dissociation of the molecular gases.

Near and above the mesopause radar observations of meteor trails indicate air motions and in some cases the atmospheric density. Even though the east-west and north-south motions are observed at points 100 to 200 km apart, time smoothing of the data can provide information on tidal and large scale motions at altitudes from 80 to 110 km with height accuracy of a few kilometers. Few efforts have been made to collate electron drifts with radiometeor trail winds or to coordinate the work of investigators in these two disciplines.

Up to 100 km, electron drifts obtained from radio reflection data may represent actual air motions, but they may also be evidence of gravity waves, radio wave veolocities, or motions of charged particles (principally electrons) which do not move with the neutral atmosphere. With altitude above 100 km, the electron drifts become increasingly independent of the neutral particle motions. Neither the height nor the thickness of the layer where the drifts occur is known with sufficient precision.

Some current aerospace vehicle programs require forecasts of atmospheric conditions between 50 and 200 km. The conditions to be forecast include not only the neutral density and motions of the air itself, but also, for radio propagation predictions, the density and motions of its electrified components (ions and electrons). To accomplish this, dependable statistics of the various properties, categorized by latitude, season, and solar cycle phase, are needed. Such statistics could be compiled from a historical series of constant-level maps and cross sections based on data from all available sources, corrected for the very considerable diurnal variations in the high atmosphere and critically evaluated to insure compatability. Only through a coordinated approach can the scientific community satisfy the present and future requirements for detailed information about the mesosphere and lower thermosphere. Such an approach is recommended for the various government agencies and scientific organizations, with due consideration being given to the requirements that our national aerospace vehicle programs place upon the meteorological discipline.****

While portions of the above statement would raise the eyebrows of today's aeronomers, as far as meteorological content is concerned, this statement is almost as valid today as it was when published twelve years ago (Teweles, 1967). Some progress has been made, however, in the routine monitoring of mesopause dynamics, and this is the subject of this report.

1.1 INTRODUCTION

This report documents the international cooperation which has been achieved in recent years in the monitoring of the mesopause using ground based techniques. Although the ionospheric drift observations coordinated by the chairman of URSI Commission III, Working Group G.2. have used a similar observational calendar, we here concentrate on the cooperation achieved between meteor wind radar (MWR) observers and incoherent scatter (IS) facilities, since this has been the main thrust of the subject grant.

1.2 Meteor Wind Radar (MWR) Observations

Although the radio meteor method of upper atmosphere wind measurement was developed almost three decades ago, the technique is still only employed to a limited extent, with some twenty stations currently operational, most being in mid-latitudes (see Appendix I for a list of stations and locations).

The radio meteor method of wind determination makes use of natural tracers--the solar orbiting meteors whose orbits intersect that of the earth, and which produce ionized trails in the earth's atmosphere between 80 and 100 kilometers altitude. These trails diffuse rapidly (the majority of echoes last less than half a second when radar frequencies of order 30 MHz are used -- echo duration decreases with frequency),but techniques have been developed which enable the reflecting center altitude to be determined to approximately 1 kilometer, and line of sight trail drift velocity (due to neutral atmosphere motion) to ± 2 m/sec. The characteristics of a meteor wind radar suitable for continuous monitoring of meospause dynamics are discussed in Section 6.

Historically, the ground-based radio meteor method of wind determination suffered a severe setback with the onset of the satellite era--investigators were in great demand in the more glamorous area of satellite technology.

Before this, some excellent work was carried out by Greenhow (1959, 1961) at Jodrell Bank in England, but this meteor wind project was discontinued in 1961. Since the early '60's, a small group at the University of Sheffield has been active (Muller, 1966). A copy of this radar has been operated by the University of the West Indies at Kingston, Jamaica. The British Meteorological Office has a station operating at Bracknell, England. Meteor wind data continues to be gathered at Adelaide, South Australia, where a group led by Dr. W. G. Elford has been working in this field since 1952. The only other southern hemisphere MWR is that of the University of Canterbury, Christchurch, New Zealand. The transmitter from the multistation radar operated by the Smithsonian Observatory at Havana, Illinois, during the sixties, was acquired by the Electrical Engineering Department of the University of Illinois, and is operational at Urbana. Also in the sixties, the U.S. Air Force, through Dr. A. A. Barnes of the Cambridge Research Laboratory, constructed radars which were located at Stanford Electronics Laboratory, Eglin Air Force Base, and the University of New Hampshire. With the complete withdrawal of the Air Force from the radio meteor field in September, 1971, only the University of New Hampshire radar continues operation. A significant contribution to mesopause dynamics has come from the French group at the National Center for Telecommunications Studies (CNET) who for many years operated a radar at Garchy, and more recently at Montpazier, on a campaign basis at Kiruna, Sweden, and in 1977 installed a portable radar at Ramey, Puerto Rico. A station is now being operated by the University of Bologna at Budrio, Italy. In addition, several stations are operating in the Soviet Union, which has placed considerable emphasis on monitoring mesopause dynamics since the early sixties. The Hydrological and Meteorological Services of the U.S.S.R. operates four stations in the European sector, and is installing new equipment in Central Siberia, and near Vladivostock. Four other meteor wind radars are operated by Soviet universities, and data has been collected at three other sites (Heis Island, 82°N; Molodeshnya, 67°S;and Mogadishu, 2°N). In Japan, a station is being operated by the Ministry of Posts and Telecommunications in Tokyo, and another has been constructed at the University of Kyoto (first routine run - December, 1977). There is a meteor wind radar in operation at Waltair, India, and in addition the Indian Space Research Organization is installing a meteor radar at Trivandrum. All the above stations, and more, are needed to provide adequate geographical coverage of the meteor wind regime.

Radio meteor winds have proved invaluable in the production of models of the lower thermosphere (see, for example, Kochanski (1971)). Meteorlogists modeling the atmosphere below the meteor region need to know how much energy is leaking out of the lower atmosphere in vertically propagating planetary waves, tidal winds, and gravity waves. Ionospheric models have to date assumed, for lack of data, that the 120 km lower bound is an isopycnic; while it has been realized for some years that this is not so, there is as yet insufficient data available, particularly on a global scale, to adequately predict the variations involved. A much better lower bound is the mesopause at 85 km--there is good evidence that this level separates a "monsoonal" mesospheric circulation below, from a more directly solar driven thermosphere above (Elford, 1974).

1.3 <u>The Incoherent Scatter Technique</u>

The incoherent scatter technique uses a very high powered pulse radar, and interprets the spectrum of Thomson scatter from the ionsphere. Incoherent scatter observations have contributed the bulk of our ground based knowledge of the magnetosphere. More recently, improvements in instrumentation have resulted in the ability to measure winds to altitudes as low as 55 km around midday. IS facilities are expensive, and only a few stations exist. National Science Foundation funding is a significant factor in the total number of stations operational--NSF supports the Arecibo Radio Observatory, Puerto Rico; Jicamarca, Peru; Millstone Hill, Massachussetts, and Chatanika, Alaska. The station operated by the U.K. at Malvern is no longer in use--it has been superceded by the European EISCAT, not yet operational. The French operate a multistatic system, with the main station at St. Santin. The Soviets are known to have an IS radar at Karkov, but details are sparse. A new facility is being planned in Japan. These stations have provided a wealth of information on ionospheric and magnetospheric parameters (temperature, in particular), and have excellent height/time resolution in determining wind profiles in the upper mesosphere and lower thermosphere. However, the logistics of their operation is such that they cannot be expected to provide routine wind measurements on a daily basis.

2.1 COORDINATED OBSERVATIONS USING METEOR WIND AND INCOHERENT SCATTER RADARS

The first attempt at coordinated observations came out of the Workshop on Methods of Obtaining Winds and Densities from Radar Meteor Tails (Barnes, 1968; Barnes and Pazniokas, 1968), where participants from six stations agreed to simultaneously observe the Geminid meteor stream in December, 1966.

Almost simultaneously, Newell and Dickinson (1967) proposed a global system for measuring meteor winds. Their proposal was taken under advisement by the Inter-Union Commission on Solar Terrestrial Physics (IUCSTP)--in April, 1970, in reporting the recommendations resulting from the International Symposium on Waves in the Upper Atmosphere (Toronto, January 19-23, 1970), in particular, the proposal of GRMWSP, the Global Radio Meteor Wind Studies Project, Professor C. O. Hines, then Chairman of IUCSTP Working Group 10, stated "Many vital advances now hinge on the acquisition of adequate data at meteor heights, wind data in particular. There is a wide-spread consensus that the meteor-radar technique should be pressed forward urgently."

These recommendations were endorsed at the XVth General Assembly of the International Union of Geodesy and Geophysics (Moscow, August, 1971). In particular, international cooperation in the measurement of radio meteor winds was consolidated in Working Group 6 of the International Association of Geomagnetism and Aeronomy, Commission VIII, to which the principal investigator was elected on August 9, 1971. With the reorganization of IAGA at its Second General Scientific Assembly in Kyoto, September, 1973, the responsibility for GRMWSP was vested in Division V, with the principal investigator co-reporter with Professor T. R. Kaiser, University of Sheffield. Also at the Kyoto Assembly, a proposal was brought by Dr. J. E. Salah, representing the International Union of Radio Science (URSI) Commission III, Working Group 8, which resulted in the URSI/IAGA Cooperative Tidal Observations Program (CTOP);

this brought together the URSI Incoherent Scatter Network, and the meteor radar stations of IAGA's GRMWSP. A detailed report of the early years of CTOP is contained in the principal investigators report to IAGA Division V, Working Group 2, presented at the Joint IAGA/IAMAP Assembly, Seattle, August 22-September 3, 1977 (see Appendix II). The mailing lists pertinent to GRMWSP/CTOP activities appear in Appendix III.

2.2 GRMWSP/CTOP Calendars

An initial prime objective of GRMWSP was to maximize the usefulness of the MWR data being gathered by proposing a calander for simultaneous observations. The first calendar resulted from the January, 1970 International Symposium on Waves in the Upper Atmosphere (Toronto, January 19-23, 1970). Subsequent calendars have been produced by the principal investigator in the September prior to each calendar year, circulated to the GRMWSP community, and finalized in November/December on the basis of feedback received. Subsequent to the first CTOP interval in August, 1974, the distribuiton list was expanded to include IS stations. In 1975, Dr. K. Sprenger, Chairman of URSI Commission III, Working Group G.2., proposed adoption of the CTOP calendar by radio wave drift observers, and subsequent calendars have included this group also.

Calendars for 1970 through 1979 appear as Appendix IV.

2.3. CTOP Meetings and Publications

Of particular relevance to these cooperative efforts was the highly successful "Symposium on E Region Winds and Electric Currents" held at the Joint IAGA/IAMAP Assembly in Seattle, August 22-September 3, 1977. Together with Dr. S. Kato, of the University of Kyoto, the principal investigator reviewed over fifty abstracts, and scheduled the two and a half day program. Subsequently, over twenty of these papers were edited in their entirety, and have been published as a special issue of the Japanese Journal of Geomagnetism and Geoelectricity, 1979.

The first CTOP publication, consisting of an overview paper and nine individual papers, written or reviewed by the principal investigator, together with co-coordinator, Dr. J. E. Salah in the Journal of Atmospheric and Terrestrial Physics for August, 1968. Titles and authors are listed in Appendix V.

2.4 Visit by Dr. Hugo Alleyne

Dr. Alleyne, Vice Dean for Science of the University of the West Indies, Kingston, Jamaica, spent a portion of his study leave at Tech during the summer of 1979. His help in preparing for the meeting of IAGA Division V, Working Group 2 (Meteor Observatories) at the upcoming IUGG Assembly in Canberra, December, 1979, and in reviewing the first draft of this report, is gratefully acknowledged. (Dr. Alleyne is in charge of the meteor wind project in the Department of Physics at U.W.I.).

3. AVAILABILITY OF DATA

One of the bottlenecks associated with dissemination of data from both radio meteor wind and incoherent scatter facilities is the tremendous volume of output from these experiments.

For many years, MWR data processing was hampered by the analog nature of the data--early systems used filming of oscilloscope patterns, which then had to be manually reduced with the aid of (initially) crude film readers and desk machine calculators. While more sophisticated readers, which punched cards or paper tape for subsequent computer processing were developed, the film processing and handling remained a major bottleneck. In the early sixties, the systems developed at Air Force Cambridge Research Laboratories by Barnes, and at Stanford by Nowak (both detailed in Barnes and Pazniokas, 1968) used a minicomputer approach, to perform online echo validation, and to produce a digital tape of echo by echo data, which was subsequently processed offline to produce winds.

Being a later development, the incoherent scatter technique produces output in computer compatible digital format. The incoherent scatter community has agreed on standard formats, and their data is being achieved at the World Data Centers.

The meteor wind radar community is only now in the process of exploring various avenues of data dissemination. Cooperation between experimenters (in both the MWR and IS communities) has proceeded on the basis of individual initiative (except for the joint publication effort detailed in Appendix V). The Soviets have taken the initiative in the matter of MWR data archiving, and have made proposals which are to be considered at the meeting of IAGA Division V, Working Group 2 (Meteor Observatories) at the XVIIth IUGG Assembly in Canberra, Australia, December, 1979.

4. THE CURRENT STATUS OF MESOPAUSE DYNAMICS

The current status of meospause dynamics is reviewed in the next few pages of this report. This material was presented at the Symposium on Stratospheric Analysis and Ozone held under the auspices of the World Meteorological Organization in Washington, D. C., July 8-13, 1979. In addition to discussion of prevailing winds, tides, the influence of stratospheric warmings on the global dynamics of the mesopause, and models, the paper also addresses the compatability of upper atmosphere wind measurement techniques.

Mesospheric and Lower Thermospheric Dynamics

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INTRODUCTION

The region between 60 and 85 km altitude (the mesosphere) has often been referred to as the "ignorosphere," in that it is above the heights sounded by conventional meteorological rockets, and below the E region, which has been monitored for decades using radio techniques.

The advent of the rocket released vapour trail in the late 1950's did little to increase our knowledge of the mesosphere, in that these sodium vapor and trimethyl aluminum releases were concentrated in the 85 to 240 km altitude range, with the exception of a few titanium tetrachloride releases in the mesosphere.

Since the early 1950's, a considerable amount of data on neutral atmosphere motions in the height range 80 to 100 km has come from the meteor radar technique (see Appendix I for list of stations and locations). However, with the notable exception of those stations operated by the Hydrometeorological Service of the U.S.S.R. (which, unfortunately do not routinely measure height, but consider all echoes as coming from a mean echo height near 95 km), the continuous operation needed to infer the synoptic meteorology of the region has been rare. The only attempt at such operation producing height/time profiles of winds between 80 and 100 km has been carried out at Atlanta (34°N, 84°W), and winds from August 1974 through December 1977 have been published by Roper (1978). While these results are valuable, being from a single station they provide only a crude insight into the synoptic meteorology of the meteor region.

PREVAILING WINDS

While considerable variability exists in the meteor winds measured by various groups, global circulation systems with seasonal variability, reproducing year after year, have been found. Analysis of several years northern hemisphere radio meteor wind data by Minina, et al., 1977, and Ilichev and Portnyagin, 1977, shows that the pressure field at meteor heights in winter is similar to the baric profile of the underlying atmosphere. During the summer, however, the lower thermosphere differs considerably from the baric profile of the mesosphere, stratosphere, and troposphere. In winter, at high and mid latitudes a cyclonic vortex with its center near the pole is observed; in summer, at latitudes greater than 65°, anticyclonic motion prevails. Cyclonic motions prevail through the year at midlatitudes, with anticyclonic circulations in the subtropics. On the average, the spring reversal of the circulation in the meteor zone occurs before that in the stratosphere--thus continuous monitoring of mesopause circulation can be used as a predictive tool in inferring the circulation of the upper stratosphere.

To date, the meridional circulation, which is of comparable strength to the zonal at meteor heights, has recieved little detailed attention. However, there does seem to exist a global system of motion from summer to winter pole, which agrees with the warm winter/cold summer mesopause inferred from high latitude rocket grenade temperature soundings.

One outstanding feature of the prevailing wind motions as deduced at midlatitudes (see, for example, Elford, 1974) is the fact that the 85 km (mesopause) level is an obvious boundary between the mesospheric circulation below, and the thermospheric circulation above.

MEAN VERTICAL MOTIONS

One of the most puzzling features of winds measured in the 80 to 100 km height range is the apparently large (meters per second) mean motion which is inferred from both incoherent scatter and radio meteor wind observations. While the large magnitude of these winds is still in question, the sign of these motions, at least as inferred from the quasi-continuous observations over Atlanta, is consistent with the general circulation (Dolas, 1979).

TIDAL WINDS

The most outstanding feature of the motions at meteor heights is the prevalence of solar tidal oscillations. On the average, more wind energy resides in tidal motions than in the prevailing circulation in the lower thermosphere.

While the irregularity of the diurnal tide, particularly in the northern hemisphere, has hampered the investigation of this tide as a global phenomenon, recent work by Mathews (1976) using the Arecibo Observatory incoherent scatter facility, and by the French with their portable meteor wind radar at Ramey, Puerto Rico (results as yet unpublished) has shown the presence of a stable, large amplitude (~50 m/sec) equinoctial diurnal tide at the equinoxes.

In the southern hemisphere (Adelaide, 35°S, 139°E), the diurnal tide has a larger average amplitude than is found at northern hemisphere midlatitudes, but both phase and amplitude are highly variable in both hemispheres.

The semidiurnal tide, by comparison, exhibits relatively constant phase, but, again, great variability in amplitude. This variability can be explained by variations in the stratospheric/mesospheric wind fields through which the tidal energy is propagating to reach the mesopause. The variability has time scales related to the planetary wave time scales in the lower atmosphere, and further understanding of these variations can only come from long period (preferably continuous) observation by a network of stations widespread in both latitude and longitude.

STRATOSPHERIC WARMINGS

It has been known for some time that the sudden warmings of the polar stratosphere which occur during some northern hemisphere winters affect the circulation at mesopause levels at high latitudes. More recent measurements at midlatitudes (Atlanta, 34°N, 84°W) have shown a direct cause/effect relationship, with major stratwarms causing zonal wind reversals (see Appendix VII). There are indications from the limited amount of data available from the southern hemisphere that northern hemisphere winter polar stratwarms may be a global phenomenon at the mesopause level.

Stratospheric warmings also affect tidal amplitudes and phases, but with a lack of continuous height/time profiles available globally, reports of such effects have been for the most part descriptive of particular locations only, and somewhat confusing in their interpretation.

MODELS

Two significant semiempirical models of stratospheric/mesospheric/lower thermospheric winds have emerged in the last decade. Groves (1970) took data from 1000 rocket launches with ejected sensors, 127 rocket grenade experiments, and 230 experiments with rocket released vapor trails and clouds, and constructed monthly mean zonal and meridional circulation patterns. This model, together with monthly mean tropospheric data, upper air global temperature maps, radio meteor winds, and the Jacchia thermospheric model have been incorporated in the Global Reference Atmospheric Model of Justus, et al. 1976.

This empirical model generates latitude, longitude, and altitude dependent monthly mean values for pressure, density, temperature and winds from surface to orbital altitudes.

Theoretical models of atmospheric tides have recently been reviewed by Forbes and Garrett (1979). While there is a measure of agreement between the latest theoretical models and observational data, since the tides are a global phenomenon, questions as to standing versus travelling waves, and latitudinal variation will not be resolved until a global network of synoptic measurement capability is established.

An additional problem in resolving theory and observation centers around the variability encountered in all meteorological phenomena. The presence of other motions besides those of primary interest, in particular, the aliasing of tidal observational data by long period (planetary) waves, and the interaction between the tides and the shorter period random internal atmospheric gravity waves, makes a widespread, continuously operating monitoring network a necessity. Such a network in the United States is proposed in Appendix VI. An ideal radar for deployment is that described by Aso, et al. (1979).

COMPATABILITY OF MEASUREMENT TECHNIQUES

While early attempts to compare winds measured by different techniques (e.g., rocket released vapor trails, radio meteor winds, airglow drifts, and partial reflections radio observations) were singularly unsuccessful, more recent comparisons, in which allowances were made for sampling differences, in particular integration intervals in both height and time, have resolved these inconsistencies (see, for example, Felgate, et al., 1975; Geller, et al., 1976; Vincent, et al., 1977; and Hernandez and Roper, 1979). As yet unpublished comparisons between the French meteor radar located at Ramey, Puerto Rico, and

Arecibo incoherent scatter facility, have shown excellent agreement. One outstanding achievement at Arecibo has been the extension of the lower limit of reliable wind determination by the incoherent scatter radar down to as low as 55 km.

The radio meteor wind technique is capable of continuously monitoring the dynamics of the 80 to 100 km altitude range, with a lower limit of observable variation of a few hours, and a height resolution of some 2 km. Specialized highpowered radars, such as that operated by the University of Illinois, can monitor variability of time constant less than one hour, but the logistics of highpowered operation preclude continuous sampling beyond intervals of a few days. The diurnal variability of meteor influx renders the error of wind determination greater at dusk than at dawn, but most facilities achieve a sufficiently high echo rate at dusk to make these results still statistically significant.

The partial reflections drift experiment is capable of sampling, with a time resolution of minutes, and a height resolution of 3 km, a height range from 60 kilometers to 110 km in daylight hours, but returns are reliably received only from 90 km up at night. The incoherent scatter technique suffers similarly from the diurnal variation of mesospheric ionization.

Rocket vapour techniques, while yielding excellent instantaneous snapshots of the stratosphere/mesosphere/thermosphere (height range governed by type of vapor released, and time of day) are prohibitively expensive if synoptic data is required. Their dependence, together with airglow observations, on cloud cover for observation is also a significant drawback.

Winds can be inferred in the stratosphere, mesosphere, and lower thermosphere by application of the thermal wind equation to satellite temperature soundings. Unfortunately, the large tidal winds at upper mesospheric heights and above, preclude the use of quasi-geostrophic approximations--the inference of viable winds from satellite temperatures at these altitudes is highly doubtful.

A further groundbased technique worthy of mention is the VHF radar technique (Rottger, et al., 1978). While not yet in routine operation, these VHF radars have demonstrated the capability of measuring winds and turbulence in the troposphere, stratosphere, and upper mesosphere.

Also, the VLF observations of Schminder and Kurschner (1979) warrant further investigation, since they appear to provide continuous, reliable observations of mesopause dynamics.

AVAILABILITY OF DATA

Beginning with the formation of GRMWSPM, the Global Radio Meteor Wind Studies Project of IAGA, in 1970, followed by the URSI/IAGA Cooperative Tidal Observations Program (CTOP), which added incoherent scatter radar observations, attempts have been made to coordinate observations (see Operating Schedule since 1970, Appendix IV). Some of these results were published in 1978 (see Appendix V for list of papers).

While data is available from individual observers, as yet formats and analysis techniques have not been standardized, and no central depository exists. The Soviet Union is moving toward having all their radio meteor wind data available through the World Data Center in Moscow. The mechanics of such archiving, both in the Soviet Union and elsewhere, are to be discussed at a meeting of IAGA Division V, Working Group 2 (Meteor Observatories) at the IUGG Assembly in Canberra, Australia, in December 1979.

ACKNOWLEDGMENTS

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5. MAP - THE MIDDLE ATMOSPHERE PROGRAM

This report would not be complete without reference to the Middle Atmosphere Program of the Special Committee on Solar Terrestrial Physics (SCOSTEP) of the International Council of Scientific Unions. Details of this program, which is designed to be to the middle atmosphere what GARP is to the troposphere and the IMS is to the magnetosphere, may be found in the Map Planning Document (available from Dr. S. A. Bowhill, Department of Electrical Engineering, University of Illinois, Illinois 61801).

Of particular relevance to this report is the proposed synoptic monitoring of the dynamics of the global mesopause. Because of the variability of the global circulation at these heights, as detailed in Section 4.1, "synoptic" in this instance means, ultimately, day by day winds, with sufficient height and time resolution to be able to determine the amplitudes and phases of the diurnal and semidiurnal tides. Such data can be collected by a network of modern meteor wind radars. Global coverage is needed to produce maps of the circulation at these altitudes, and this requires international cooperation. A large gap in coverage exists east of Japan, and west of the eastern United States. A MWR network which would, at least partially, fill this gap is proposed in Appendix VI.

While the major thrust of MAP has been delayed until 1982-85, pre-MAP programs are underway. Pre-MAP 1, which has as it focus a better understanding of the effect on the upper atmosphere of winter polar stratospheric warmings, was held during the northern hemisphere winter of 1978-79. A concerted effort to better understand the phenomenon of anomalous radio wave absorption in the D region is planned for 1980-81, with the West Germans spearheading an international rocket program to make in situ measurements in the mesosphere during the winter of 1980-81. Radio meteor and incoherent scatter observations during these special periods have and will provide vital knowledge of the dynamics of the upper mesosphere and lower thermosphere, a knowledge crucial to the understanding of these "anomalous" events.

If MAP is to be a success, coordinated observations, such as those carried out under GRMWSP and CTOP, will be an absolute necessity.

6. THE "IDEAL" METEOR WIND RADAR

The "ideal" meteor wind radar measures the following parameters:

1. The line of sight drift of the trail
2. The direction of arrival of the echo from the trail
3. The range of the trail from the observing site
4. The time of each echo (year, day, hour, minute, second).

If we confine ourselves to consideration of a continuously operating (24 hours a day, 7 days a week, 52 weeks a year) radar, measuring prevailing winds, diurnal and semidiurnal tides, an echo rate of 1000 useable echoes a day will provide adequate height/time resolution, provided height (from parameters 2 and 3 above) is measured to ±2 km or better. Such an echo rate can be achieved with an average transmitter power output of the order of 1 kilowatt. CW radars, such as those used at Adelaide and Atlanta, and initially by the French at Garchy, have the advantage of high signal to noise ratio (because receiver bandwidths can be limited to less than 100 Hz), but suffer from interference from aircraft echoes, and require separation of transmitter and receiving sites. CW radars also have a lower limit to line of sight drift measurement--most trails decay before the doppler frequency can be measured for line of sight drifts less than some 10-15 m/sec. However, a decided advantage can be realized from the phase stability point of view--with a groundwave continually present at the receiving antennae, phase changes in the individual direction finding receivers and antenna systems have practically no effect on arrival angle determination.

A pulse system developed at Adelaide in the 1950's, and used for a limited time at Mawson, Antarctica, overcame the conventional pulsed radar phase coherence difficulties by feeding a CW signal, coherent with the transmitted pulse, to an antenna located a few hundred feet from the direction finding array. By offsetting this coherent signal by some 40 Hz, the minimum drift velocity limitation can be removed, and replaced by a maximum velocity limit of some 150 m/sec away from the receiving site. In my experience, such a line of sight velocity magnitude has never been observed.

Obviously, minicomputer or microprocessor control of the radar, with data validated, digitized and written out on magnetic tape, is a state of the art requirement.

For locations requiring a single site, or where aircraft interference could be a problem, the radar best meeting these requirements is that currently being operated at the University of Kyoto (Aso, et al., 1979). This radar, however, uses Yagi antennas and an interferometer technique for direction finding, with post receiver reference phase injection. An all sky direction finding system, with relative phases established by a "ground wave" at the antennas, would obviate the phase stability problems associated with post receiver reference phase injection. Such a system is currently under development at Georgia Tech.

7. CONCLUSIONS

Definite pluses have resulted from this grant; in particular, the first CTOP collected papers in JATP, and the Seattle symposium, with papers published in JGG.

However, while the need for international cooperation during specific intervals is important, particularly in association with short term , concerted rocket campaigns, and for collaboration between meteor wind and incoherent scatter radar observations of the upper mesosphere and lower thermosphere, as far as meteor winds are concerned, the major advances being made are the result of continuous operation.

Unfortunately, the majority of meteor wind radars are operated by universities, and have problems with both funding and personnel which make continuous, long term operation almost impossible. Only in the Soviet Union, where a MWR network is manned and funded by the Hydrometeorological Service, are synoptic observations carried out. Unfortunately, these stations do not measure echo height, which limits the usefulness of their data (assurances are that this limitation will eventually be overcome).

While the single station continuous observations carried out in Atlanta continue to demonstrate the worth of this mode of operation, significant advances in understanding the dynamics of the mesopause will only result if a network of continuously operating radars is set up. Such a network covering the U.S. (for example, as proposed in Section 4 and Appendix VI), should come under the auspices of a government agency whose mission is routine, long term monitoring of the atmosphere, such as the National Oceanic and Atmospheric Administration, rather than a research oriented agency such as the National Science Foundation.

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APPENDIX I

List of Meteor Wind Radar (MWR) Measuring Stations

Meteor Radar Station	Location	Status	Freq. (MHz)	Peak Power	Pulse (μ sec)	PRF	REMARKS
Hayes Island (Arctic)	81 N 55 E	S	33.5	75 kw	20	500	
Kiruna (Sweden)	68 N 20 E	S	30		CW		Portable version of Garchy
College (USA)	65 N 148 W	S	30.2 +	750 w	CW		±390 Hz
Moscow (USSR)	59 N 37 E	U	33	100 kw	10	500	
Stornoway (U.K.)	58 N 6 W	S	36.3	20 kw	25	300	Portable version of Sheffield
Tomsk (USSR)	57 N 85 E	S	30.0	50 kw	5	600	
Obninsk (USSR)	56 N 38 E	R	25.2	75 kw	20	500	*
Gorky (USSR)	56 N 44 E	U	36.9	75 kw	10	500	
Kazan (USSR)	56 N 49 E	R	33.5	120 kw	5	780	
Kuhlungsborn (Germany)	54 N 12 E	U	32.55	40 kw	30	500	
Jedrell Bank (U.K.)	53 N 2 W	SN	36.3	100 kw	20	150	
Sheffield (U.K.)	53 N 1 W	R	36.3	200 kw	25	300	*
Bracknell (U.K.)	51 N 1 W	S	36.3	20 kw	30	300	Copy of Sheffield
Eindhoven (Netherlands)	51 N 5 E	U	40				
Ondrejov (Chekosloyakia)	50 N 14 E	R	37.5	25 kw	10	500	No Doppler yet
Kiev (USSR)	50 N 31 E	R	34.5	10 kw	10	500	
Kharkov (USSR)	50 N 36 E	R	36.9	100 kw	15	500	
Carchy (France)	47 N 3 E	R	29.7968	5 kw	CW		29.7976; 29.7920
Pullman (USA)	47 N 117 W	P					Copy of Eglin
Mayaki (USSR)	47 N 33 E	U					IGY, Odessa
Simferodol (USSR)	45 N 34 E	U					IGY
Montpazier (France)	44 N 1 E	R	30		CW		Portable version of Grachy
Bologna (Italy)	44 N 11 E	R	42.7	50 kw	10	140	*
Florence (Italy)	44 N 11 E	N	39.5	15 kw	16	150	No Doppler
London, Ontario (Canada)	45 N 81 W	R	40	0.1 kw	CW		
Durham (USA)	43 N 71 W	R	36.8	30 kw	40	488	*
Frunze (USSR)	43 N 75 E	R	39.5	40 kw	8	100	
AFCRL (USA)	42 N 71 W	SN	36.8	30 kw	40	488	
Havana (USA)	40 N 90 W	SN	40.9	3 Mw	5	750	Moved to Urbana
Urbana (USA)	40 N 88 W	R	40.9	3 Mw	5	750	*
Dushanbe (USSR)	38 N 69 E	S	a) 37.4	75 kw	10	500	
			b) 17.6	20 kw	100		
			c) 73	50 kw	10	100	
Accomack (USA)	38 N 76 W	N	36.8		CW		
Stanford (USA)	37 N 122 W	SN	30.14	5 kw	280	300	
Ashkabad (USSR)	37 N 59 E	S	33.7				
Atlanta (USA)	34 N 84 W	R	32.5	1.7 kw	CW		*±360 Hz
Tokyo (Japan)	36 N 140 E	R	37.46	20 kw	10	300	*

Meteor Radar Station	Location	Status	Freq. (MHz)	Peak Power	Pulse (μ sec)	PRF	REMARKS
Kyoto (Japan)	35 N 136 E	R			280	300	*
White Sands (USA)	33 N 106 W	S	32.8	50 kw		400	
Eglin (USA)	31 N 87 W	SN	36.8	5 kw	280	300	
Ramey (Puerto Rico)	18 N 67 W	R	30		CW		*Portable version of Garchy
Kingston (W. Indies)	18 N 77 W	R	36.4	20 kw	35	100	Copy of Sheffield
Andhra (India)	18 N 84 E	S	36.3	20 kw	25	300	Copy of Sheffield
Trivandrum (India)	8 N 78 E	P					
Mogadishu (Africa)	2 N 45 E	S	36.9	40 kw	40	500	
Gan	1 N 73 E	P	36.3	20 kw	25	300	Proposed copy of Sheffield
Adelaide (Australia)	35 S 139 E	R	26.773	1.5 kw	CW		*27.5 MHz; 65 kw, 8 μs pulse
Christchurch (N. Zealand)	44 S 172 E	R	27.1	40 kw		150	
Molodezhnaya (Antarctic)	67 S 45 E	S	33	35 kw	pulse		
Mawson (Antarctic)	68 S 67 E	SN	34	15 kw	10	750	

Status

N = no longer operating; P = proposed; R = regular operation; S = some data available; U = unknown

APPENDIX II

Report on IAGA Div V Working Group 2
(Meteor Observatories)

Presented at the Joint IAGA/IAMAP
Assembly, Seattle, Aug 22 - Sept 3, 1977

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IAGA Division V, Working Group 2
(Meteor Observatories)

Report presented by R. G. Roper at the
Joint IAGA/IAMAP Assembly, Seattle, August 22 - September 3, 1977

As with my first report as chairman of this working group (presented at the Grenoble IUGG meeting in 1975), most of this report is addressed to radio meteor wind determination. However, one of the reasons why I suggested that the initially proposed group title "Radio Meteor Observatories" be changed to "Meteor Observatories" was that I envisaged the group as serving not only IAGA's self interests, but also as a liason with other associations and Unions with an interest in meteor astronomy and meteor physics, particularly as these relate to interactions with the earths atmosphere. In this context, members of W. G. 2 have participated in a joint IAU/IAGA "Committee on Radar Observations of Meteor Rates and Radiants, and Anomalies at the Base of the Thermosphere". Since the interest of IAU Commission 22 (the original proposers of the Joint Committee) lie solely in the meteor patrol (rates and radiants) area (as reported by Chairman C. S. L. Keay at the Grenoble Assembly of IAU in August 1976), our input to this committee has been minimal

However, close ties have been forged with experimenters using other techniques; in particular with the Incoherent Scatter Group G. 8 of URSI Commission III through the joint Cooperative Tidal Observations of the Lower Thermosphere Program (CTOP), and the Ionospheric Drift Observations Group G. 2 of URSI Commission III who, together with IAGA's Global Radio Meteor Wind Studies Project (GRMWSP), are now using the same observational calendar.

Reports have been received detailing the most recent operations of the Italian CNR Meteor Radar Station at Budrio (44.5° N, 11.7° E)(Dr. F. Verniani) and of the iminent completion of an excellently conceived meteor wind radar by the Ionosphere Research Laboratory of the University of Kyoto (Dr. T. Aso).

Communications have been received from Dr. A. Frost (University of New Hampshire) and Dr. D. Rind (Lamont Doherty Geological Observatory) concerning the use of infrasound recording techniques to deduce the wind field in the lower thermosphere. They are anxious to make comparisons with radio meteor and other lower thermosphere wind determinations.

The URSI/IAGA CTOP venture has resulted in the following papers, detailing results of the first three cooperative periods (9-14 August, 1974; October 13-17, 1975; January 19-23, 1976), which are being considered for publication in the Journal of Atmospheric and Terrestrial Physics:

Roper, R. G., and J. E. Salah, "Preliminary Results from the URSI/IAGA Cooperative Tidal Observations Program (CTOP)".

Harper, R. M., and R. H. Wards, "Coordinated Tidal Observation at Arecibo".

Roper, R. G., "Winds from the Atlanta (34° N, 84° W) Radio Meteor Facility".

Hess, G. C., and M. A. Geller, "Urbana Meteor Radar Observations During GRMWSP/CTOP Periods".

Clark, Ronald R., "Meteor Wind Data for Global Comparisons".

Ward, R. H., and J. E. Salah, "Tidal Observations at Millstone Hill for the August 1974 and October 1975 Special Periods".

Kingsley, S. P., H. G. Muller, L. Nelson, and A. Scholefield, "Meteor Winds Over Sheffield (53° N, 2° W)".

Glass, M., R. Bernard, J. L. Fellows and M. Massebeuf, "The French Meteor Radar Facility".

Bernard, R., "Incoherent Scatter Results for Coordinated Special Intervals at St. Santin, France".

Baggaley, W. J., and E. M. Poulter, "The Radio Meteor Wind Facility at Christchurch, New Zealand".

With the publication of the SCOSTEP Middle Atmosphere Program (MAP) Planning Document (available from the Aeronomy Laboratory, Department of Electrical Engineering, University of Illinois, Urbana, Illinois 61801, U.S.A.), which calls for greatly increased cooperation between experimenters using ground based, in situ and satellite techniques, an even greater need exists for such collaborative endeavours as GRMWSP and CTOP.

At our working group meeting last Tuesday night, discussions centered around the need for longer observational intervals in order to determine the importance of day to day variability on a global scale. To this end, a primary Global Observational Interval, June 1 to June 14, 1978, was proposed for CTOP.

To increase our knowledge of equatorial upper atmosphere dynamics, the French portable radar has been located at Puerto Rico as part of a colaborative program with the incoherent scatter facility at the Arecibo Observatory.

At the working group meeting, discussions were held with Ray Conkright of World Data Center A regarding the archiving of radio meteor wind data. A proposed data format will be circulated by the chairman later this year.

APPENDIX III

Mailing Lists

MAILING LIST FOR GRMWSP

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PLUS

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APPENDIX IV

GRMWSP/CTOP Calendars

INTERNATIONAL UNION OF GEODESY AND GEOPHYSICS
INTERNATIONAL ASSOCIATION OF GEOMAGNETISM AND AERONOMY

Dr. R.G. Roper,
School of Geophysical Sciences
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GLOBAL RADIO METEOR WIND STUDIES PROJECT
(GRMWSP)

OPERATING SCHEDULE

1970	January 27 - February 6
	March 16 - March 29
	April 20 - April 30
	June 8 - June 20
	September 21 - October 6
	October 12 - October 23
	December 9 - December 15
1971	February 8 - February 19
	May 10 - May 21
	June 7 - June 12
	July 19 - July 30
	August 9 - August 14
	September 13 - September 24
	October 4 - October 15
	December 6 - December 17
1972	*Denotes Second Priority Intervals
	January 24 - February 3
	March 13 - March 31
	*April 17 - April 22
	*May 15 - May 20
	June 5 - June 30
	*July 24 - July 29
	*August 7 - August 12
	September 25 - October 6
	October 16 - October 27
	*November 13 - November 18
	*December 11 - December 16

1973 January 15 - January 27

*February 12 - February 17

March 12 - March 24

*April 16 April 21

*May 14 - May 19

June 4 - June 24

*July 16 - July 21

*August 13 August 18

*September 17 - September 22

October 15 - October 31

*November 12 - November 17

*December 17 - December 22

1974 January 14 January 26

April 16 - May 7

August 7 August 22

(August 9-14 was designated as the first URSI/IAGA Cooperative Tidal Observation Program (CTOP) interval, with the URSI Incoherent Scatter Net cooperating with GRMWSP)

October 23 - November 14

1975 A new priority system was introduced

M Radio Meteor Observations

I Incoherent Scatter Observations

D Ionspheric Drifts

G Global experiment (all techniques)

M January 27 - February 11

MID February 11 - February 14

MD April 7 - April 25

I June 10 - June 12

I August 12 - August 13

D September 1 - September 19

G October 13 - October 17

MD November 3 - November 16

I December 13 - December 15

1976	W	Spans Winter Anamoly efforts by the Germans in Spain and the U.S. at Wallops Island
	MW	January 12 - January 30
	G	January 19 - January 23
	M	April 12 - April 23
	G	April 13 - April 15
	M	July 12 - July 23
	G	July 13 - July 15
	M	September 20 - September 24
1977	MD	January 7 - January 21
	G	January 18 - January 19
	MD	March 14 - March 18
	G	April 19 - April 22
	MD	June 6 - June 17
	G	June 14 - June 15
	MD	September 12 - September 16
	MD	December 5 - December 16
	G	December 6 - December 9
1978	G	March 2 - March 15
	G	June 1 - June 14
	G	July 27 - August 9
1979	G	January 10 - January 24
	G	March 14 - March 28
	GP	Highest priority interval of the year March 20 - March 28
	G	September 12 - September 26

Cooperation with ionspheric drift stations coordinated through 1977 with Dr. K. Sprenger, Chairman URSI Commission III, Working Group G.2., subsequently succeeded by J. W. Wright.

APPENDIX V

CTOP Papers in JATP

Papers published in the Journal of Atmospheric and Terrestrial Physics, August, 1978

Preliminary Results from the URSI/IAGA Cooperative Tidal Observations Program (CTOP) - R. G. Roper and J. E. Salah

Coordinated Tidal Observations at Arecibo - R. M. Harper and R. H. Wand

Winds from the Atlanta (34°N, 84°W) Radio Meteor Wind Facility - R. G. Roper

Urbana Meteor Radar Observations during GRMWSP/CTOP Periods - G. C. Hess and M. A. Geller

Meteor Wind Data from Global Comparisons - Ronald R. Clark

Tidal Observations at Millstone Hill for the August 1974 and October 1975 Special Periods - R. H. Wand and J. E. Salah

Meteor Winds over Sheffield (53°N, 2°W) - S. P. Kingsley, H. G. Muller, L. Nelson and A. Scholefield

The French Meteor Radar Facility - M. Glass, R. Bernard, J. L. Fellous and M. Massebeuf

Incoherent Scatter Results for Coordinated Special Intervals at St. Santin (France) - R. Bernard

The Radio Meteor Wind Facility at Christchurch, New Zealand - W. J. Baggaley and E. M. Poulter

APPENDIX VI

Proposed U.S. MWR Network

APPENDIX VI

Suggested plan for implementation of Synoptic Observations of Mesopause Dynamics over the U.S.A.

1980-81	Construct and field test prototype radar at Georgia Tech	$150,000
1981-82	Construct and deploy an additional 6 of these continuous operation radars at University of New Hampshire University of Illinois, Urbana Washington State University ERL Boulder, Colorado. San Diego Hawaii	$550,000
1982-	Maintenance and Operation ($30,000 per site, plus additional $40,000 at headquarters site for data reduction and publication)	$250,000 per annum

APPENDIX VII

The Effects of Polar Stratwarms on the Winds at the Mesopause Level in Mid Latitudes

APPENDIX VII

Reprinted from Preprint Volume: 18th Conference on Radar Meteorology, Mar. 28-31, 1978, Atlanta, Ga. Published by the American Meteorological Society, Boston, Mass.

THE EFFECTS OF POLAR STRATWARMS ON THE WINDS AT THE MESOPAUSE LEVEL IN MID LATITUDES

R. G. Roper

School of Aerospace Engineering
Georgia Institute of Technology
Atlanta, GA 30332

1. INTRODUCTION

For over a quarter of a century, winds have been measured over the height range 80 to 100 km by means of radio reflections from the ionized trails of meteors. Although sophisticated high frequency radars (usually operating in the 20 to 40 MHz range) have been employed, not all of the advantages of the technique have been realized. In particular, very few continuous, long term observations have been made. In the past, the major problem has been an inability to handle the large amount of data generated by continuous operation. However, the revolution in data acquisition in recent years had made such operation economically feasible.

2. THE METHOD

The radio meteor method of wind determination has been described at a previous AMS Radar Meteorology Conference (Barnes, 1972), and the Georgia Tech Radio Meteor Wind Facility detailed by Roper (1975). The Tech system is a continuous wave radar (using two continuously transmitted carriers 720 Hz apart to determine range) designed to measure some 1000 line of sight dopplers and echo positions per day. However, since the CW technique accepts echoes at all ranges, aircraft reflections are a problem, at times reducing the rate below 300 echoes per day. This, together with time lost through maintenance of the transmitter and receivers, occasional power outages at the receiving site, and the need to average several days data to produce meaningful measurements of the diurnal and semidiurnal tides, results in an apparent smoothing of the data of from a few days to two weeks. In order to meet the publication deadline, consideration is given here only to the zonal mean wind; analysis of the significance of the meridional and vertical mean winds, and the tidal winds, is proceeding.

3. RESULTS

Continuous radio meteor wind observations commenced over Atlanta in August, 1974. Figure 1a shows the variation with height and time of the zonal wind 80 to 100 km over Atlanta for the period November, 1974 through February, 1975. In interpreting the structure present, the averaging interval details in Figure 1b should be taken into consideration.

An attempt was made to correlate the observed winds with the zonal mean satellite rad-

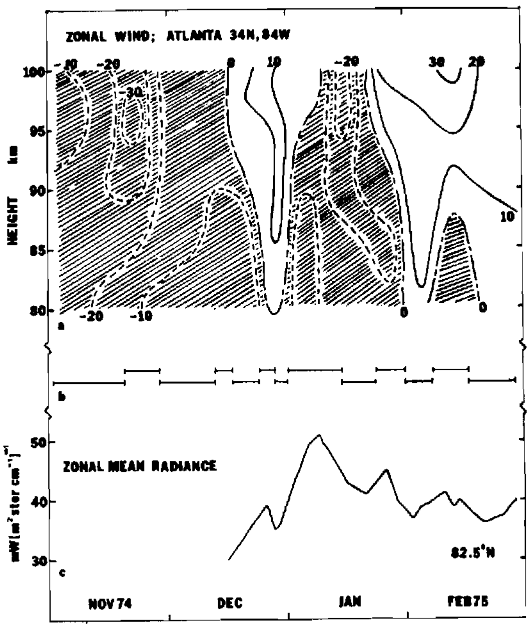

Figure 1a) The mean zonal wind over the height range 80 to 100 km above Atlanta for the period November, 1974 through February, 1975. The zonal means to which the contours have been fitted are averages for the measurement intervals depicted in b). c) is the zonal mean radiance deduced from satellite radiometer measurements, and is proportional to the stratospheric temperature averaged over the 100 to 5 mb height range at 82.5°N.

iance data at 82.5°N published by Quiroz et al (1975). The late December/early January warming did not produce a wind reversal at the 10 mb level, therefore is not characterized as a major warming.

The circulation at meteor heights during the fall and early winter of 1974, being predominantly easterly (as plotted, a negative wind is a wind vector directed toward the west, i.e. an easterly), is unusual, at least when compared to subsequent years (see Figures 2 and 3). About the best one can say from this preliminary comparison of the meteor winds with the single zonal mean radiance data curve is that there are wind reversals which

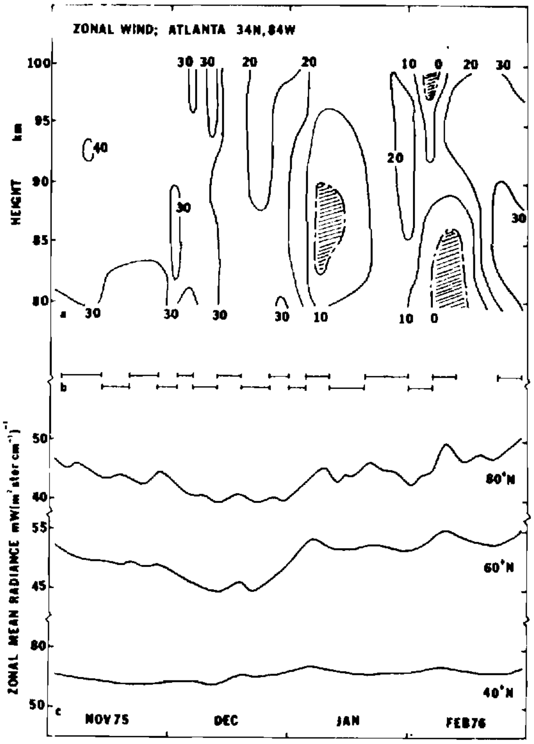

Figure 2. As for Figure 1 for November, 1975 through February, 1976, except that the zonal mean radiance is presented for three latitudes, and is proportional to the stratospheric temperature averaged over the 100 to 2 mb height range.

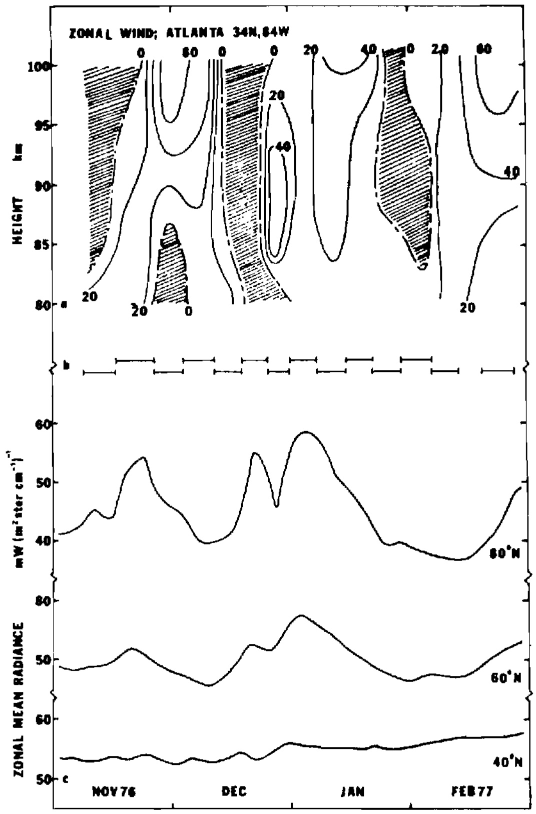

Figure 3. As for Figure 2, for November, 1976 through February, 1977.

correlate with the changes in radiance.

Proceeding to the winter of 1975-76 (Figure 2), the zonal flow at meteor altitudes is predominately westerly, with two minor reversals - in early January, and early February. Comparison with the zonal mean radiance satellite data, this time available for three latitudes (Quiroz, private communication, 1977) shows that there are local maxima in the radiance curves at all three latitudes during these two periods. However, there are not any outstanding features in the radiance data - no warmings occurred curing the winter of 1975-76.

The data for the winter of 1976-77 represents the most interesting set to date. Unfortunately, no meteor wind data is available for the first week in November (and the last week in October). However, the winds through August, September and mid October were consistently westerly - thus the change to easterly in mid November could well be associated with the warming of late November. With the reestablishment of westerlies over the whole height range by the end of November, the onset of the late December warming is preceded by a rapid waning of the westerly at the upper levels, with the onset of easterly flow above 90 km occurring a week before the winds at 80 km become easterly. During the last week in December, the satellite radiance data show a reversal of the latitudinal temperature gradient from that established by the warming. This is accomplished by what one would almost call a westerly "jet" in the mid height range of the meteor winds. The subsequent warming trend in early January is not accompanied by a meteor wind reversal, and just so that we will not be tempted to think that we have all the answers, there is a tongue of weak easterlies which descends from 100 km to 83 km in late January/early February, which seems to have no correlation with the stratospheric temperature curves.

4. CONCLUSIONS

The continuous measurement of the wind profile over the 80 to 100 km region by means of radio reflections from meteor trails provides data which can be correlated with stratospheric temperature changes inferred from satellite radiance data. The very preliminary results presented here (later publications will include the consideration of the meridional wind, as well as the diurnal and semi-diurnal tidal winds) show a tendency for stratospheric warming events (which produce zonal mean temperature changes in the stratosphere at 40°N which are only just measurable) to produce dramatic changes in the circulation in the neighborhood of the mesopause at 34°N. While such changes have previously been expected and reported at higher latitudes (see, for example, Hook, 1970), to my knowledge this is the first report of similar behavior as far south as 34°N.

5. ACKNOWLEDGMENTS

Special thanks are due to Dr. R. S. Quiroz, of the National Meteorological Center, Washington, D.C., for providing the satellite radiance data

used in Figures 2 and 3, prior to their publication.

The Georgia Tech Radio Meteor Wind Facility was initially funded by the Georgia Institute of Technology. Since 1971, it has been funded by the Atmospheric Research Section of the National Science Foundation under grants GA26626 and ATM75-14414. Data analysis and interpretation is supported by the National Aeronautics and Space Administration under grant NGL-11-002-004.

6. REFERENCES

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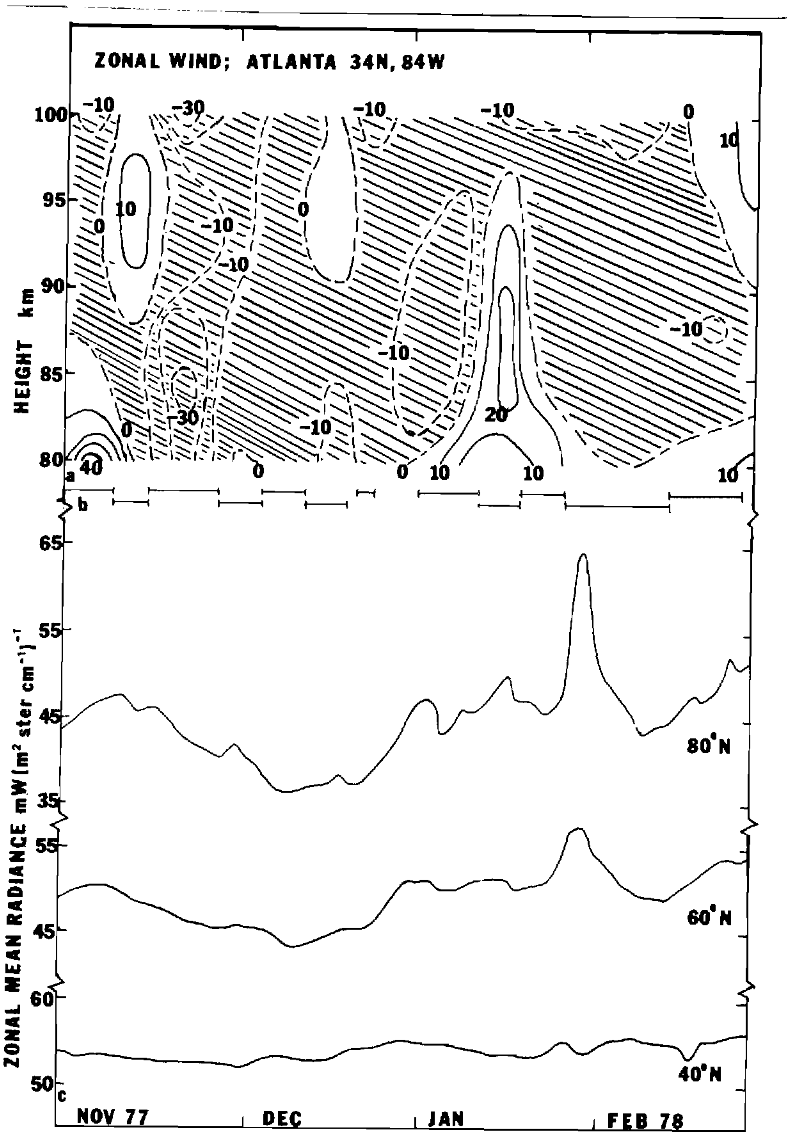
Hook, J. L., "Winds at the 75 to 110 km level at College, Alaska", Planet. Space Sci., 18, 1623-1638, 1970.

Quiroz, R. S., Miller, A. J., and Nagatani, R. M., "A comparison of observed and simulated properties of sudden stratospheric warmings", J. Atmos. Sci., 32, 1723-1736, 1975.

Roper, R. G., "The measurement of meteor winds over Atlanta (34°N, 84°W)", Radio Science, 10, 363-369, 1975.

Added for discussion at the AMS Upper Atmosphere Conference, Boston, Mass. October 24-27, 1978



APPENDIX VIII

Protocol for Inviting Soviet Scientists to International Meetings

APPENDIX VIII

Protocol for Inviting Soviet Scientists to Meetings

While the attendance of two Soviet Scientists at the Seattle Assembly (out of six invited), may have been fortuitous (in ten years I have been at only one other meeting outside the U.S.S.R. at which the Soviet meteor wind community was represented), the following information, gleaned at the Grenoble IUGG Assembly in 1975, is, I believe, necessary protocol.

a) invitations must be sent at least eight months in advance.

b) in addition to an invitation to the individual scientist, letters requesting the approval and assistance of

c) the invitees Institutional Head (Departmental Chairman, Laboratory Director, etc.) and

d) the Soviet Geophysical Committee, are mandatory. If one knows under which Soviet Ministry the invitee's institution operates (Ministry of Education for universities, for example), a letter to the Ministry would not hurt.

We cannot blame the Soviets for lack of attendance at meetings if we do not take account of the procedures required by their government for a travel request to be authorized.

Evidence of Soviet willingness to cooperate is contained in the letter from the Soviet Geophysical Committee on the next page.

АКАДЕМИЯ НАУК СССР

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№ 644

« 28 » November 1977 г.

Dr. R.G.Roper,
Chairman, WG V-2 IAGA
School of Aerospace Engineering
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Atlanta, Ga. 30332
U.S.A.

Dear Dr. Roper,

Many thanks for the information about the activity of Working Group V-2 IAGA and about the meteor calendar for 1978, and also for the invitation to cooperate on the middle Atmosphere Program in 1978.

The Soviet Geophysical Committee of the USSR Academy of Sciences considers useful the participation of Soviet research organisations in that project and would accordingly make recommendations to these organisations.

The Committee also asked these organisations to send in results of meteor drift observations for the periods: 9-14 Aug. 1974; 13-17 Oct. 1975; 19-23 Jan. 1976 and 5-16 Dec. 1977. The Committee shall arrange forwarding of observation materials for these periods to the World Data Center B.

The correct address of Dr. V.V.Fedynsky is:

Soviet Geophysical Committee
Molodezhnaya 3
117296 Moscow, USSR

Please make corresponding correction in your list.

Sincerely yours,

Prof. J.D.Boulanger,
Vice-President
Soviet Geophysical Committee